Changes in the concentration and size-distribution of the sub-micron particles associated with the sea- and land-breezes at a coastal station

P. Murugavel and A. K. Kamra*

Indian Institute of Tropical Meteorology, Dr Homi Bhaha Road, Pashan, Pune 411 008, India

Surface measurements of the size-distribution of sub-micron aerosol particles in the range of 0.003 to 1 μm diameter have been made on 6–8 January 1998, at Thiruvananthapuram during an inter-comparison campaign of the Indian Ocean experiment (INDOEX). The results are studied with respect to the setting-in of the sea- and land-breezes at the station. Observations show an increase of up to an order of magnitude in aerosol concentrations of all size categories with the setting-in of the land breeze at 1800–1900 IST. High concentrations of aerosol particles prevail throughout the period of the land breeze at night-time. Aerosol concentrations remarkably decrease at about 1000 IST with the arrival of much cleaner air with the sea breeze. During the land breeze at night-time, the size-distributions of aerosol particles is bimodal with the maximum at 0.075 and 0.024 μm diameters. During the sea breeze, especially in the afternoon, the maximum in the accumulation mode shifts to a slightly higher size (0.133 μm) and the maximum in the nucleation mode seems to shift to a smaller size (0.013 μm or smaller). The size-distribution curves during the daytime are mostly open-ended at the small particle-size end. The enhanced coagulation of aerosol particles and the gas-to-particle conversion processes have been proposed to explain the shift of maxima in the accumulation mode and the enhanced generation of small particles in the nucleation mode in the afternoon, respectively.

IN the absence of seasonal strong surface winds, the coastal stations, especially in the tropics, often experience the meso-scale meteorological phenomena of the reversal of winds from offshore to inshore (sea breeze) and from inshore to offshore (land breeze). These phenomena are the consequences of the land–sea thermal contrast arising out of the different heat capacities of the land and ocean. The onset of sea- and land-breeze are generally associated with sharp changes in the surface values of temperature and relative humidity[1]. Convergence zones associated with the onset of the sea breeze may lead to the formation of a sea breeze front with a sharp boundary[2]. These zones produce horizontal convergence and vertical updrafts over the coastal land which may cause recycling of pollutants[3,4]. Land breeze, on the other hand, may cause advection of warm air over the warmer marine boundary layer causing haze due to the convergence accumulation of aerosols[5]. Studies on accumulation of aerosol particles during sea- and land-breezes are therefore, important for the dispersion of aerosols over coastal areas. For example, Krishna Moorthy *et al.*[6] report from their optical depth measurements at Thiruvananthapuram that sea breeze fronts are associated with a significant enhancement in columnar loading with aerosol particles. Lyans and Oerson[7] and Keen and Lyons[3] have studied the response of the shoreline industrial exhaust to the lake breeze from Lake Michigan.

In this paper, we report our measurements of the size-distribution of sub-micron aerosol particles measured at the surface level at Thiruvananthapuram (8°33′ N, 76° 57′E), a tropical coastal station, during the pre-INDOEX intercomparison campaign during 6–9 January 1998. The diurnal variation in the concentration of aerosols and their size-distribution with respect to the effects of land- to sea-breeze on them are discussed.

Instrumentation

The EAA system of TSI Inc is used to measure the aerosol concentration in the size-range of 0.003 μm to 1.0 μm diameter in 10 different size-ranges. It works on the principle of diffusion charging-mobility analysis[8]. The ambient air is sampled at a rate of 50 lpm. It is first exposed to a Kr-85 radioactive neutralizer and then passed through a mobility analyser which contains concentric cylindrical electrodes and a central collector rod. A pre-determined voltage is applied between these electrodes to produce an electric field in the condenser. The charged particles are deflected towards the collector rod by this electric field and the concentration of aerosol is measured in terms of a mobility spectrum. The details of the instrument are

*For correspondence. (e-mail: kamra@tropmet.ernet.in)

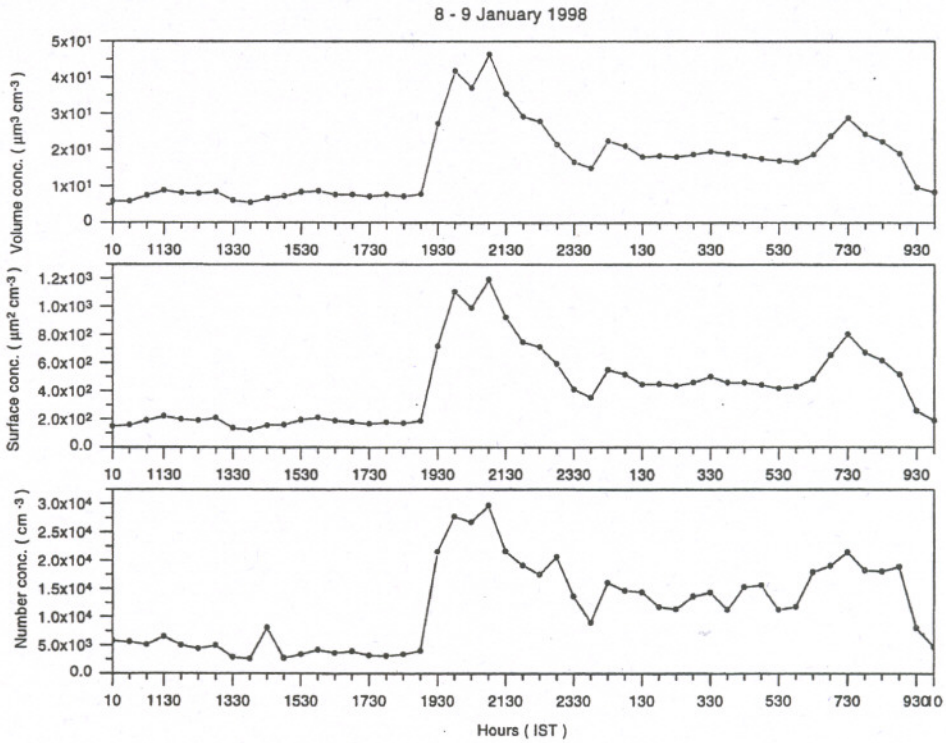

Figure 1. Diurnal variation of number, surface and volume concentrations of aerosol particles.

described elsewhere[8,9]. The instrument is interfaced with an IBM-286 PC and is controlled through a program.

Weather

The site of observation is a plain coastal land at Vikram Sarabhai Space Centre, Thiruvananthapuram approximately 500 m inland off the sea coast and is close to the sea level. Observations show that from November to April, this place is favourable to sea breeze activity[10,11]. During this period, it experiences land breeze during 2100–0900 IST approximately and sea breeze during the rest of the day.

The air is sampled at 1 m height above the ground. Care is taken to avoid the condensation in the inlet tube during high humid period and the inlet tube is cleaned periodically. The observations are made from 0900 to 2030 h and throughout the day on 8–9 January 1998. Five sets of size-distributions are obtained at each half-an-hour interval.

Observations

Figure 1 shows the diurnal variations of the total number, surface and volume concentrations of aerosol particles for a 24 h period on 8–9 January 1998. The diurnal variations of aerosol number concentrations in different size-ranges for the same time period are shown in Figure 2. The aero-

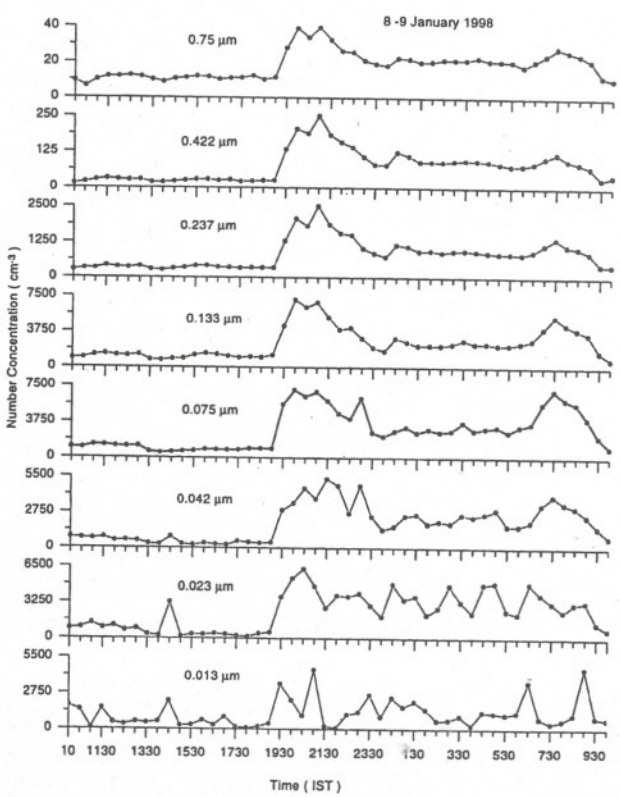

Figure 2. Diurnal variation of number concentration in different diameter size of aerosol particles.

sol concentration in all the size-ranges is low during the day from 1000 to 1900 h and suddenly increases after 1900 h. Average values of the total aerosol concentration during 1000 to 1900 h are 4325 particle/cm^3 and during 2000 to 0900, 17045 particles/cm^3. The initial increase in aerosol concentration at 1900 h is sudden and large and these large values continue to exist for 3 to 5 h and then decrease to approximately half their value. However, throughout the night, these values continue to remain significantly higher than their daytime values. The percentage differences in the daytime and night-time values of particle concentrations is relatively smaller in the smallest size-range with mean size of 0.013 μm as compared to other size-ranges. The aerosol concentration in all size-ranges again shows an increase at about 0600 h before coming to the daytime low value at 0900 h.

Although size-distribution of particles are measured at each half-an-hour interval, to avoid crowding in Figure 3, the curves for only hourly observations are plotted. The half-hourly in-between samples follow the similar trends. Size-distribution curves for daytime and nighttime observations form two quite distinct groups. Size-distributions are generally bimodal with their maxima at 0.075 and 0.024 μm during night-time (1900 to 0900 h). After 0900 h, the curves significantly lower down but mostly remain bimodal up to 1400 h with slight shift in maxima in the accumulation mode towards the higher size. During daytime, especially in the afternoon hours from 1400 to 1800 h, the shift in maxima in the accumulation mode to a higher diameter (0.133 μm) is distinct and the maxima in the nucleation mode seems to shift to smaller diameter (0.013 μm or smaller). As a result of the increase in the

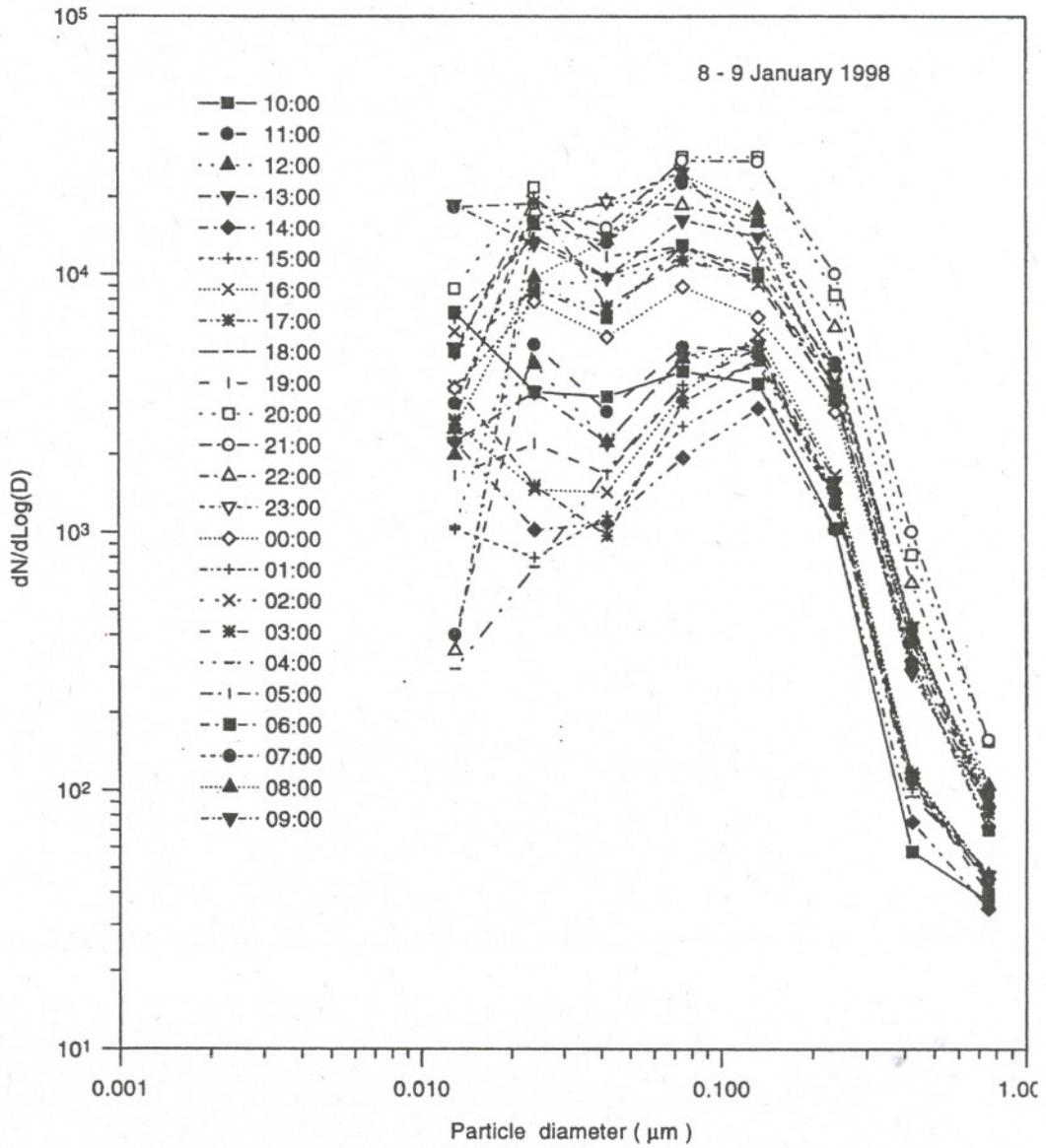

Figure 3. Size distribution of aerosol particles in the size range 0.013–0.75 μm diameter.

concentration of small particles, the size distribution curves during daytime are mostly open-ended at the small-particle side.

We have described our observation only for 8–9 January 1998. However, the trends in the concentrations and size-distributions of aerosol particles during the period of observation on other days show almost similar trends of diurnal variation.

Discussion

Our observations effectively demonstrate the cleansing effect of the sea breeze for surface aerosols in the submicron range over the coast. The prevailing wind during the day from 1000 to 1800 h at this station is the sea breeze. Slowly, the wind becomes calm and changes its direction. Land breeze sets in at 1900 h. The sudden enhancement in particle concentration at 1900 h is closely associated with the change in the wind direction. This effect has also been observed earlier[6,12]. Higher concentrations of aerosol particles observed during the first few hours of the wind direction reversal are perhaps due to the accumulation of particles in the stagnant air over the land. Similarly, somewhat increased values of aerosol concentrations in the morning hours may result because of their reduced advection from land to ocean as the convergence zone shifts closer to the coast.

Aerosol particles over the coast are a mix of the marine and land aerosols. Throughout the period of the land breeze at night-time, size-distributions of aerosol particles remain bimodal. In the presence of solar radiation during the daytime, the production of small particles in the nucleation mode due to gas-to-particle conversion processes becomes prominent. Consequently, the particle size-distributions, especially in the afternoon, show relatively higher concentrations of small particles and become open-ended at the small-particle end. The systematic transition of particle size-distributions to bimodal nature in the evening hours confirms the role of gas-to-particle conversion processes in generating small particles in the nucleation mode.

Due to relatively larger convective velocities and the enhanced level of turbulence during the daytime, the aerosol particles have larger residence time in the atmosphere. Therefore, they get more time to coagulate and grow to larger sizes before depositing to the surface. The shift of maxima on larger size in the daytime size-distribution curves of aerosol particles confirms this hypothesis.

1. Bornstein, R. D. and Thompson, W. T., *J. Appl. Meteorol.*, 1981, **20,** 843–858.
2. Hunt, J. C. R. and Simpson, J. E., *Engineering Meteorology* (ed. Plate, E. J.), Elsevier, 1982, pp. 269–318.
3. Keen, C. S. and Lyons, W. A., *J. Appl. Meteorol.*, 1978, **17**, 1843–1855.
4. Ogawa, Y., Ohava, T., Wakamatsu, S., Diosey, P. G. and Uno, I., *Boundary-Layer Meteorol.*, 1986, **35**, 207–230.
5. Parvanov, O., Kolev, I., Kaprielov, B., Polianov, V. and Korchev, G., Abstracts, 14th Int. Laser Radar Conf., Innichen-San, Candido, Italy, ICLAD/IRC/IAMAP, 1998, pp. 49–52.
6. Krishna Moorthy, K., Krishna Murthy, B. V. and Prabha R. Nair., *J. Appl. Meteorol.*, 1993, **32**, 1196–1205.
7. Lyons, W. A. and L. E. Olsson, *Mon. Weather Rev.*, 1973, **101**, 387–403.
8. Whitby, K. T. and Clark, W. E., *Tellus*, 1966, **18**, 573–586.
9. Benjamin, Y., Liu, H. and David, Y. H., *J. Aerosol Sci.* 1975, **6,** 249–264.
10. Narayanan, V., *Indian J. Meteorol. Geophys.*, 1967, **18**, 497–504.
11. Nair, S. and Narayanan, V., *Mausam*, 1980, **31,** 409–414.
12. Parameswaran, K., Rajeev, K. and Sen Gupta, K., *J. Atmos. Terr. Phys.*, 1997, **59**, 1727–1737.

ACKNOWLEDGEMENT. We thank the authorities of INDOEX for their participation in the Inter comparison compaign.